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Preliminary range-resolved detection of stable water isotopologues by differential absorption lidar using a 2 μm parametric source

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Abstract: We present a differential absorption lidar based on a single-frequency parametric source operating at 2 μm which was used for range-resolved measurements of the stable water isotopologues H_2^{16}O and HD^{16}O . © 2022 The Author(s)

1. Introduction

Differential absorption lidar (DIAL) is a remote gas sensing technique based on the use of tunable narrow-linewidth sources emitting radiation in and out of tune with the absorption line of the species of interest. To perform sensitive, range-resolved gas measurements, these sources need to deliver high peak power in the nanosecond regime [1]. A potential application for such a device is the measurement of stable water isotopologues in the lower atmosphere, which would lead to improved understanding of processes governing the global hydrological cycle, with the prospects of improving the accuracy in the predictions made by atmospheric general circulation models [2]. So far, despite the latest advances on multispecies DIALs [3] and a first, recently reported demonstration of the possibility to probe isotopic water vapor lines [4], no DIAL instrument has been able to quantify the relative abundance in HD^{16}O (δD), which requires collocated measurements of both isotopologues H_2^{16}O and HD^{16}O . This can however be realized around 1.98 μm , as we theoretically demonstrated in [5]. Based on these considerations, we realized a parametric source operating at 1.98 μm and performed a first demonstration of range-resolved probing of the water isotopologues H_2^{16}O and HD^{16}O .

2. Parametric source and DIAL setup

The laboratory parametric source architecture is pictured in Fig. 1a. It is based on a nested-cavity optical parametric oscillator (NesCOPO) [6] combined with optical parametric amplification (OPA) stages, pumped by a commercial Nd:YAG laser (Innolas), delivering 12 ns-pulses at a repetition rate of 150 Hz. The NesCOPO allows the emission of a single-frequency radiation, tunable in a 1 nm-window around 1982.5 nm suitable for addressing H_2^{16}O and HD^{16}O .

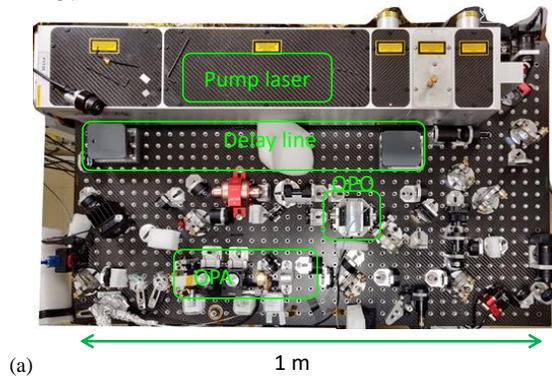


Fig. 1. (a) Experimental bench of the parametric laser source. (b) Transverse beam profile at the laser bench output

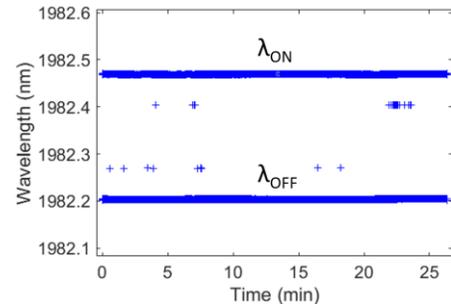


Fig. 2. $\lambda_{\text{ON}} / \lambda_{\text{OFF}}$ recorded wavelength switching for HD^{16}O measurement

The NesCOPO emitted wavelength is pulse-to-pulse modulated and recorded with a High Finesse WS6 IR wavemeter (Fig. 2). For each targeted species (H_2^{16}O and HD^{16}O), such pulse-to-pulse wavelength modulation is

necessary to emit the two wavelengths (namely λ_{ON} and λ_{OFF}) in and out of coincidence with the absorption line. This is performed by adjusting the NesCOPO cavity length using piezoelectric transducers. The OPA stage is based on three high-aperture ($5 \times 5 \text{ mm}^2$) PPKTP crystals [7]. With a pump energy of 70 mJ, and idler rejection between the last two crystals, it was possible to obtain output signal energies in the range of 6–9 mJ. A transverse profile of the output beam after passing through a beam expander is shown in Fig. 1b. It is Gaussian with a measured $M^2 < 1.5$ and a divergence full-angle of $300 \mu\text{rad}$. The lidar receiver consists of a 10-inch, custom-made Newtonian telescope which focuses the backscattered radiation onto a $900 \mu\text{m}$ -multimode fiber, whose output is imaged onto a commercial InGaAs amplified photodiode ($300 \mu\text{m}$ diameter). The telescope full-field-of view angle is 1.2 mrad .

3. Preliminary testing of water isotopologues detection by DIAL

DIAL tests along a horizontal path were conducted on 16 April 2021 in Palaiseau, France. The upper panels of Fig. 3 show the recorded ON/OFF lidar signals expressed as signal-to-detection-noise ratio (SNR), with a dominant noise contribution from the transimpedance amplifier. The lower panels of Fig. 3 show the retrieved volume mixing ratios (VMR). The signals were averaged over 30 minutes successively for each species. For H_2^{16}O , a reference was provided by an in-situ Picarro analyzer, located in the vicinity of the lidar instrument.

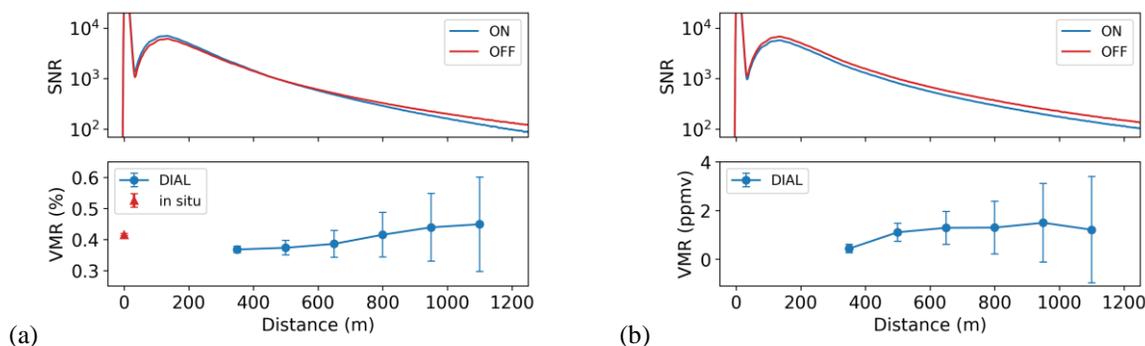


Fig. 3. Raw (no energy normalization) averaged DIAL signals over 30 min and retrieved VMR for H_2^{16}O (a) and HD^{16}O (b).

This DIAL experimental demonstration on water isotopologues is a first important step towards range-resolved δD quantification in the vertical direction. For this purpose, future work will focus on the characterization of the DIAL errors and biases as well as on increasing the power performance of the transceiver, as outlined in [7], for higher sensitivity.

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References

- [1] B.J. Orr, "Infrared LIDAR Applications in Atmospheric Monitoring" in *Encyclopedia of Analytical Chemistry* (R.A. Meyers (Ed.), 2017).
- [2] H. C. Steen-Larsen, C. Risi, M. Werner, K. Yoshimura, and V. Masson-Delmotte, "Evaluating the skills of isotope-enabled general circulation models against in situ atmospheric water vapor isotope observations," *J. Geophys. Res. Atmospheres* **122**, 246–263 (2017).
- [3] G. A. Wagner, and D. F. Plusquellic, "Multi-frequency differential absorption LIDAR system for remote sensing of CO_2 and H_2O near $1.6 \mu\text{m}$," *Opt. Express* **26**, 19420–19434 (2018).
- [4] S. Yu, Z. Zhang, H. Xia, X. Dou, T. Wu, Y. Hu, M. Li, M. Shanguan, T. Wei, L. Zhao, L. Wang, P. Jiang, C. Zhang, L. You, L. Tao, and J. Qiu, "Photon-counting distributed free-space spectroscopy," *Light Sci Appl* **10**, 212 (2021).
- [5] J. Hamperl, C. Capitaine, J.-B. Dherbecourt, M. Raybaut, P. Chazette, J. Totems, B. Grouiez, L. Régalia, R. Santagata, C. Evesque, J.-M. Melkonian, A. Godard, A. Seidl, H. Sodemann, and C. Flamant, "Differential absorption lidar for water vapor isotopologues in the $1.98 \mu\text{m}$ spectral region: sensitivity analysis with respect to regional atmospheric variability", *Atmos. Meas. Tech.*, **14**, 6675–6693 (2021).
- [6] A. Godard, M. Raybaut, M. Lefebvre, "Nested Cavity Optical Parametric Oscillators – A Tunable Frequency Synthesizer for Gas Sensing" in *Encyclopedia of Analytical Chemistry* (R.A. Meyers (Ed.), 2017).
- [7] J. Hamperl, J. F. Geus, K. M. Mølster, A. Zukauskas, J.-B. Dherbecourt, V. Pasiskevicius, L. Nagy, O. Pitz, D. Fehrenbacher, H. Schaefer, D. Heinecke, M. Strotkamp, S. Rapp, P. Denk, N. Graf, M. Dalin, V. Lebat, R. Santagata, J.-M. Melkonian, A. Godard, M. Raybaut, and C. Flamant, "High Energy Parametric Laser Source and Frequency-Comb-Based Wavelength Reference for CO_2 and Water Vapor DIAL in the $2 \mu\text{m}$ Region: Design and Pre-Development Experimentations", *Atmosphere* **12**, 402 (2021).